

A Fast Chopper for Intensity Adjustment of the Heavy-Ion Beams

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*This work was supported by the U.S. Department of Energy, Office of Nuclear Physics, under Contract No. W-31-109-ENG-38.

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A FAST CHOPPER FOR INTENSITY ADJUSTMENT OF HEAVY-ION BEAMS*

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Abstract

Several heavy-ion accelerators are being developed worldwide. It is desirable to provide simultaneous beam delivery to multiple users that can be efficiently implemented using a combination of rf-sweepers and DC magnets. A fast chopper can be used to modulate cw beam intensity by chopping away individual bunches at low beam energy. The major issue of fast choppers is the excessive power requirements from the voltage pulsers. By providing high wave impedance, ~ 200 Ohm, of a traveling wave structure one can reduce the power requirements for the fast voltage pulser. Several design options of high-impedance structures are discussed.

INTRODUCTION

To enable beam intensity adjustment in the Rare Isotope Accelerator Facility [1] we propose to use a fast chopper in the Medium Energy Beam Transport (MEBT) section. Several design options for the fast chopper were discussed in ref. [2]. The MEBT beam optics should be designed to accommodate and match the chopper technical specifications. The most elegant solution of the beam intensity adjustment of the RIA driver linac requires the chopper parameters listed in Table 1. As is seen, the voltage requirement is similar to the SNS chopper [3], however, the repetition rate is significantly higher. A high repetition rate of 12 MHz is provided in the ATLAS chopper [4] but the voltage ~ 0.8 kV is too low for the RIA application. Below we discuss three possible ways to reduce power requirements for the voltage pulser (or modulator).

Table 1: Basic parameters of the chopper

Parameter	Value
Beam velocity	0.02c
q/A	28/238
Length	60 cm
Voltage	± 1.8 kV
Pulse rise/fall time	12 nsec
Pulse length	5-40 nsec
Repetition rate	28.75 MHz
Duty factor	Up to 75 %

TRAVELING WAVE CHOPPER

A fast traveling wave chopper (TW-type) can be used to modulate cw beam intensity. Such a device should have high frequency characteristics at high power level. The modulator power can be estimated by the expression:

$$P \approx D_F \frac{1}{K(Z_w)^2} \frac{U^2}{Z_w}, \quad (1)$$

where D_F is the duty factor, $K(Z_w) < 1$ is the efficiency factor of the deflecting plates and depends on the design of traveling wave structure. There is an optimum value of the impedance Z_w which results in lowest power of the modulator. The upper limit of Z_w is due to reduction of the efficiency factor. It can be seen from figure 1 which shows a rectangular pulse of the deflecting field $E_y = \frac{U}{A}$ propagating in the traveling wave structure with aperture A for different values of impedance and aperture.

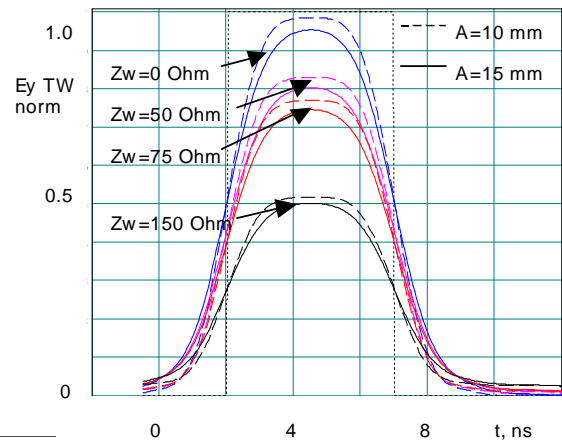


Figure 1: Deflecting field pulse in TW structure with different wave impedance (Z_w) and aperture (A).

* Work supported by CRDF Grant and the U.S. Department of Energy, Office of Nuclear Physics, under Contract No. W-31-109-ENG-38.
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For the beam parameters shown in Table 1 the optimal wave impedance is $150 \div 200$ Ohm and required modulator power will be $5 \div 10$ kW. The existing [5] and proposed [6] planar deflecting plates have lower impedance $Z_w = 50$ Ohm and are located in vacuum. However, low impedance TW structures will require significantly higher modulator power. The possible design of the deflecting plates for the RIA driver linac is shown in Fig. 2. The strips of the TW structure are connected with the spiral delay line. The wave impedance is $Z_w = 200$ Ohm. The deflecting strips are in vacuum while the spiral delay line is in air. The latter simplifies cooling of the structure. Detailed studies have shown that the ringing of the voltage pulse in the structure is a few nanoseconds and within specifications of 12 ns rise/fall time. Semiconductor switches available from industry [7] can provide 10 kV switching during a few nanoseconds.

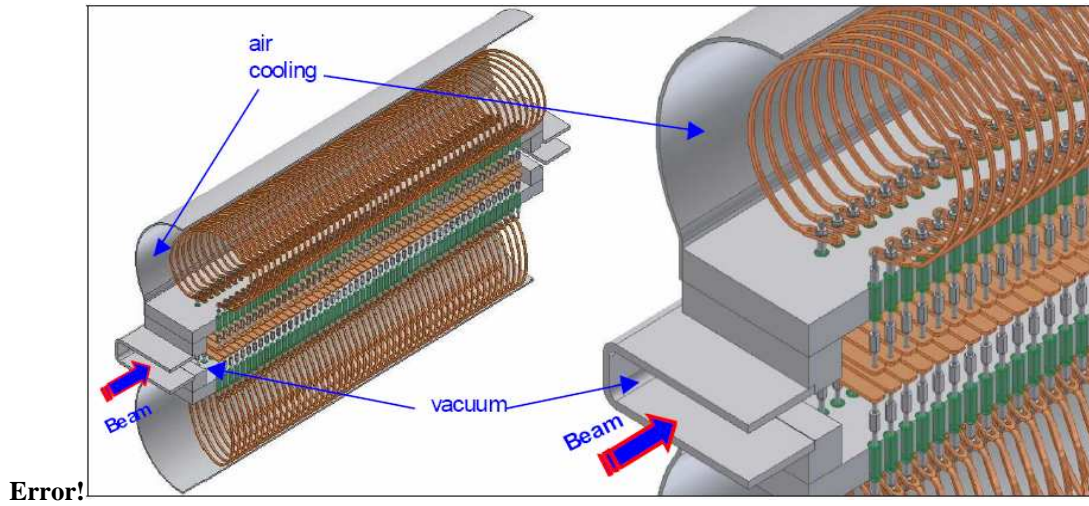


Figure 2: The traveling wave chopper design.

Switching of the modulator voltage with the rate 28.75 MHz can be built by using parallel connection of the fast switches.

A CHOPPER WITH C-TYPE DEFLECTING PLATES

To provide a voltage pulse moving synchronously with the beam, each strip of the deflecting plate can be fed from an individual modulator. Each modulator is loaded by a strip capacitance therefore it can be called a C-type chopper. Synchronization with the beam is provided by the corresponding time-delay of the voltage pulse of each modulator. A parasitic capacitance of connecting wires and modulators is a major contribution to power requirement of the modulator. It is difficult to reduce parasitic capacitance below 10 pF. The deflecting strips and connecting wires form a transmission line. The voltage pulse from the modulator should be matched to the capacitive load to prevent parasitic oscillations. Figure 3 illustrates time evolution of the voltage pulse in the capacitive load for matched and unmatched conditions. Required power of the individual modulator is defined by the effective impedance that is limited by the rise/fall time of the pulse. An advantage of C-type chopper is the possibility to adjust the velocity of deflecting field propagation along the beamline. It can be important for deflecting of ion beams at different velocities.

A CHOPPER WITH LC-TYPE DEFLECTING PLATES

One of the effective ways to reduce the modulator power is to use an LC-type chopper. The spiral delay line is replaced by the outside solenoids or toroids (Fig. 4). To reduce a dispersion effect the toroids should be located on both sides of the strips as is shown in Fig. 4. The strips with capacitance C_c and outside toroids with inductance L_c form a delay line with parameters:

$$Z_w = \sqrt{\frac{L}{C}}, \quad \beta_w = \frac{1}{c\sqrt{LC}}. \quad (2)$$

Here $L_c = L \cdot l_c$ and $C_c = C \cdot l_c$, where l_c is the length of spatial period of the deflecting strips along the beamline. To synchronize the deflecting field propagation with the beam velocity $v = \beta c$, a condition $\beta_w = \beta$ must be satisfied. Parameters of the LC-type chopper for $\beta_w = \beta = 0.02$ are presented in Table 2. The impedance of the LC-structure can be more than 300 Ohm owing to higher efficiency factor $K(Z_w)$ in expression (1). The latter is caused by more favorable dimensions of the strips and its spatial period. For LC-type structures the dispersion at high frequencies becomes noticeable. The

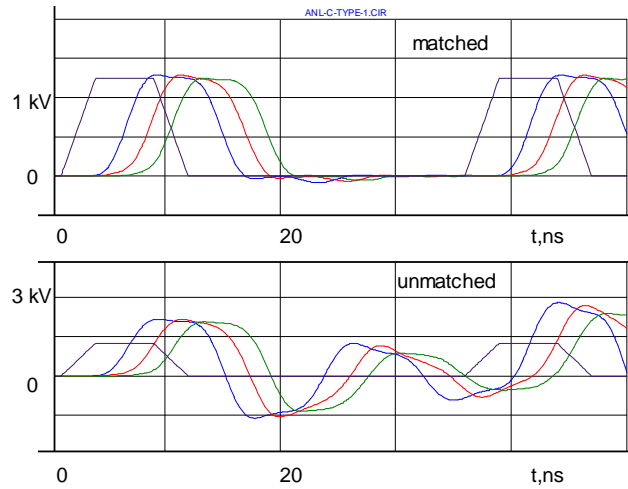


Figure 3: C-type chopper excitation. The graphs show time evolution of the trapezoidal pulse loaded by a capacitance for the matched (the top graph) and unmatched (the bottom graph) conditions.

Table 2: Parameters of the LC-chopper.

Z_w , Ohm	150	200	250	350
C , nF/m	1.11	0.83	0.67	0.48
L , μ Hn/m	25.0	33.4	41.7	58.4

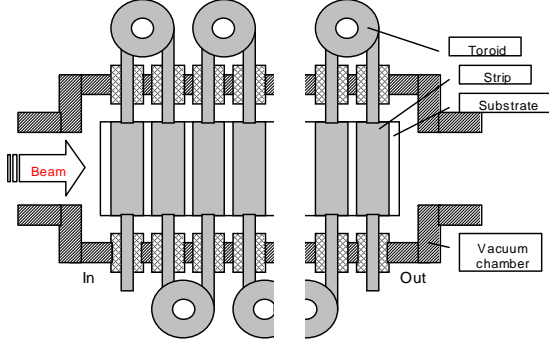


Figure 4: LC-type chopper with two-side toroid connection.

LC-structure transient time (T_{LC}):

$$T_{LC} \approx \sqrt{L_c C_c} = \frac{l_c}{\beta c}, \quad (3)$$

depends on cell inductance and capacitance and must be several times less than the specified rise/fall time of the voltage pulse. The dimensions of the cell elements must be considerably less than the cut-off wave length $\lambda_c = 4ct_f$. For example, $\lambda_c \approx 60$ cm for $t_f = 5$ ns rise-time. Typical amplitude-frequency characteristics (AFC) at different points along the LC-type deflecting plates are shown in Fig. 5.

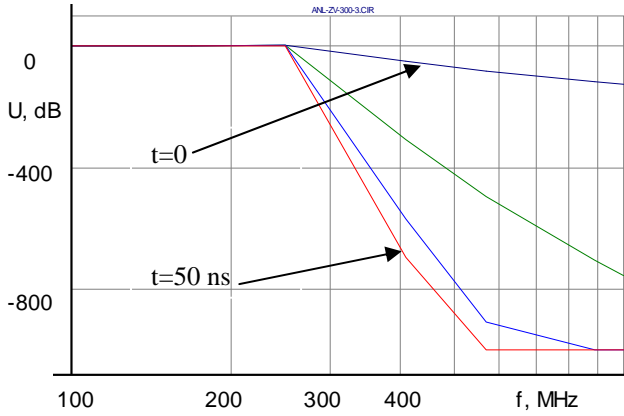


Figure 5: Typical AFC of the LC-type chopper. Different curves correspond to different time.

The high attenuation of the signal is seen from Fig. 5 on frequencies higher than ~ 250 MHz. This frequency can be called a critical frequency of the LC-structure. The signal attenuation at frequencies higher than critical frequency increases along the LC-structure. It causes a forming of damped oscillations or ringing of the voltage pulse moving along the LC-structure. To avoid parasitic ringing of the voltage pulse, frequency spectrum of the modulator pulse must be limited by the critical frequency of the LC-structure as is shown in Fig. 6. The graph on the top corresponds to the modulator pulse with 1 ns rise/fall time, while the bottom graph corresponds to 5 ns.

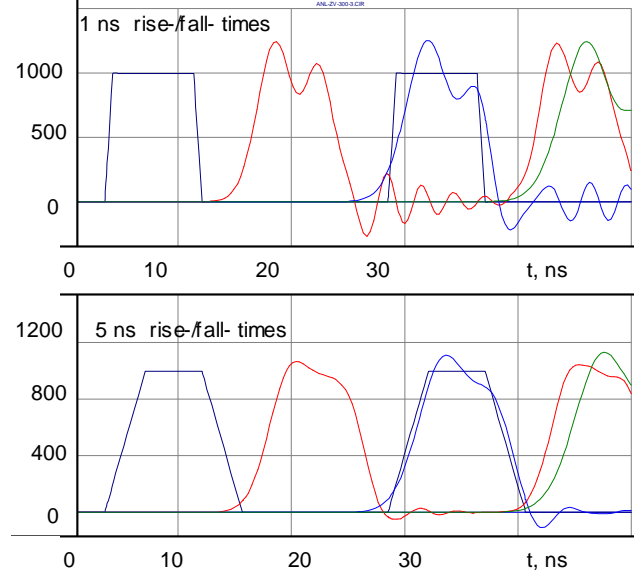


Figure 6: The LC-type chopper excitation by two different types of voltage pulse. The curves with different color show the voltage propagation along the LC-structure.

CONCLUSIONS

Intensity adjustment of cw ion beams can be performed by a fast chopper. Our goal was to investigate possible methods to reduce required power. The proposed design of TW-type deflecting plates with impedance ~ 200 Ohm will operate at reduced power. Even more power reduction can be achieved by using LC-type structure.

In some cases using a C-type chopper may be appropriate. This type of chopper can have effective impedance ~ 300 Ohm and provide ~ 12 nsec rise- and fall-time of the deflecting voltage. A sequence of C-type choppers can be synchronized to deflect ions moving with different velocities. However, to obtain sufficient deflection of beams, many individual modulators are required.

A prototyping of the fast chopper systems is required to make final decision.

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